

FACTORS INFLUENCING THE INSTANT SOLUBILITY OF MILK POWDERS

SUMMARY

High concentrations of milk solids in the aqueous phase in contact with dissolving milk powder particles render part of their constituents insoluble. This effect has been studied by measuring the amount of milk powder dissolved by volumes of water swept through mixed beds of sand and milk powder as well as beds of sand, water, and milk powder. From a consideration of the increases in solubility occurring as the spatial concentration of powder particles in the beds was decreased, and the decrease in solubility when the water content of the powders in the beds was increased, it was concluded that maximum solubility by self-dispersion can be obtained only with milk powders having bulk densities of less than 0.4 g/ml. Higher bulk densities seem incompatible with instant self-dispersion. Milk solids rapidly lose solubility if their moisture content ranges from approximately 15 to 38%. This unstable range broadens with the increase in the time the milk solids are in contact with the water.

The basic research and development done to increase the ease with which milk powders may be reconstituted has been reviewed by Pyne (8). It is surprising that this relatively large body of work gives little consideration to the deleterious changes in the solubility of milk proteins which can result from their encountering high concentrations of salts and sugar during rehydration.

It is a common observation that, in atmospheres of high humidity, milk solids rapidly form friable masses difficult or impossible to disperse. Similar effects are observed when high-density milk solids are poured onto water at a rate faster than they can be stirred into solution.

Howat et al. (3) actually demonstrated that the observed solubility of milk powder was more dependent on the rate of stirring than on the duration of the stirring period. We believe that this beneficial effect of increased stirring rate can be related to a more rapid reduction of the solids concentration in the vicinity of the dissolving milk powder particles. Similar improvement should be observed in systems in which the milk solids are mechanically fixed in such positions that the formation of high local solids concentrations during rehydration can be minimized. A low bulk density powder would represent such a system.

This paper will briefly report a series of

simple experiments which demonstrate the influence of local solids concentration on the solubility of milk powder and substantiate the idea that the bulk density of milk solids is an important limiting factor to be considered in the production of self-dispersing milk powders.

METHODS AND MATERIALS

The milk powder solubility determination devised for use in this study permitted a relatively accurate control of the amount of water in contact with the milk solids, the time of contact, and the rate of movement of the aqueous phase across the surface of the particles. This was done by using a vacuum of constant pressure to pull an aliquot of water uniformly through a sample of powder dispersed in a nonsoluble, hydrophilic supporting agent.

In one series of experiments, 5-g samples of the powder under investigation were thoroughly mixed into weighed amounts of Ottawa¹ sand. The amounts of sand used ranged from 10 to 80 g. Each sand-powder mixture was placed on a coarse sintered glass disc sealed into the bottom of a straight-walled glass funnel having an internal diameter of 9.5 cm. After smoothing the upper surface, the sand-powder mixture was covered by a piece of Whatman¹

¹ Use of trade names is for the purpose of identification only, and does not imply endorsement of the product or its manufacturer by the U. S. Department of Agriculture.

No. 2 filter paper having a diameter similar to that of the inside of the glass funnel. This assembly was then attached by means of a standard filter flask to a vacuum tank having a controlled pressure of 16 cm Hg. The vacuum was applied to the powder bed immediately after a 50-ml aliquot of 20 C water was dumped onto its filter paper-covered surface. Approximately 1 sec was required to pull the water through the layer of sand and milk powder. The amount of milk solids dissolved during transit of the aqueous phase was determined in the filtrate by the Mojonnier method (6).

In a second series of experiments, designed to further study the effect of local solids concentration on milk powder solubility, known amounts of water were stirred into 60-g samples of sand before the 5-g samples of milk powder were dispersed into it. The solubility of the milk solids in the sand-water-powder mixture was immediately determined as indicated above and after holding the mixture at 20 C in an airtight container for 48 hr.

Bulk density was determined by measuring the volume occupied by 10 g of milk powder in a 100-ml graduate cylinder after lightly tapping to constant volume.

The Ottawa sand used in these experiments was obtained from the Fisher Scientific Company, Silver Spring, Maryland, and was classed as 20-30 mesh.

The milk powders studied were all commercial samples obtained in local markets except the vacuum dried whole milk foam, prepared according to the methods of Sinnamon et al. (9). In view of the fact that the members of each class of powder investigated were so similar in properties, only part of our results is reported. The spray dried whole milk powder used in this report had a bulk density of 0.59 g/ml, the instantized nonfat powder 0.31 g/ml, and the foamed whole milk powder 0.16 g/ml. All whole milk powders contained approximately 26% fat.

RESULTS

The effect of increasing the distance between individual powder particles during the rehydration process is shown in Figure 1. Here the net effect of increasing the amount of sand in the system is to decrease the concentration of milk solids in the vicinity of the dissolving powder particles. It can be seen, from this graph, that as the spatial dispersion of the milk powder particles is increased their solubility improves. When considering powders of the same composition, greatest solubility improvement is noted with powders of high bulk

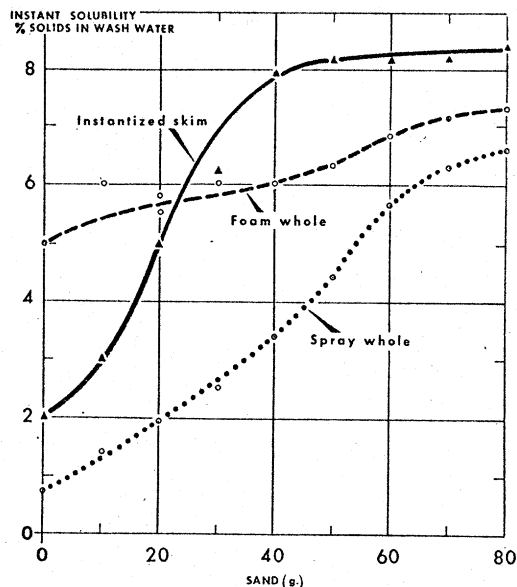


FIG. 1. Effect of adding increasing amounts of sand (decreasing spatial milk powder particle concentration) to a mixed bed of milk powder and sand on the solubility of the powder particles therein.

density. The foam-dried material which has the lowest bulk density benefits least by increasing its spatial dispersion in sand. Figure 1 also demonstrates that all powders move towards the theoretical limit of dispersibility as the concentration of solids in the vicinity of the dissolving particles is reduced. The indicated difference in the solubility plateau values shown by the curves may represent changes in milk constituents incurred during manufacture or compositional differences. It is evident that the whole milk powders are more difficult to solubilize than the nonfat product tested.

The deleterious effect of high local solids concentration on the solubility of milk powder is also illustrated in Figure 2. These data, taken from a study in which a vacuum-dried whole milk foam powder was used, are actually representative of all powders studied. In interpreting results it is assumed that the water in the water-sand mixture resides primarily in contact with the milk solids. Microscopic examination of the sand-water-powder mixture showed that this assumption is justified. The possible monomolecular film of water on the sand surfaces would not influence the reported results. From Figure 2 it can be seen that the milk solids remain dispersible only if their moisture content is held below approximately 15% or is rapidly brought up to levels higher than 62%. As the time between contact of the

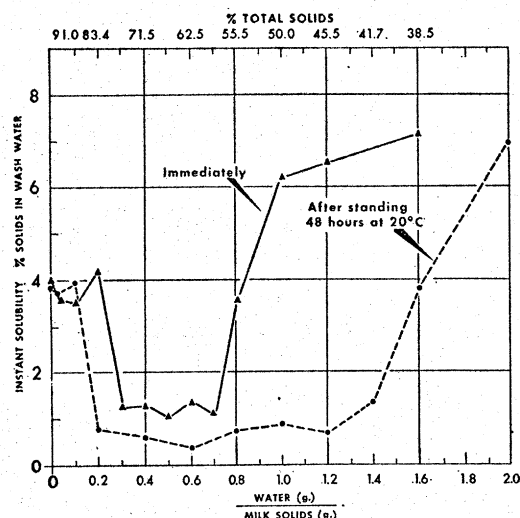


FIG. 2. Effect of the moisture content of wet milk solids on their solubility as determined immediately after wetting and 48 hr thereafter. The per cent moisture in the wet powders can be obtained by subtracting the total solids values from 100%.

milk solids with water and final solubilization is increased, the water content range in which loss of solubility occurs increases.

A short extrapolation of the data presented in Figure 2 indicates that the maximum milk solids stability during reconstitution would occur in systems whose solids concentrations did not exceed approximately 33%. At this point the system would contain 1 g milk solids and 2 g of water. The density of nonfat milk solids as reported by Lea et al. (4) is 1.44 g/ml. This density is equivalent to a specific volume of 0.69 ml/g. The volume occupied by a powder whose structure was such that the filling of the voids with water would result in a 33% solid in solution would be $2 + 0.69 = 2.69$ ml. The bulk density of a powder of this type would be 1 g/2.69 ml or 0.37 g/ml. Similar calculations, using Lea's reported density for whole milk solids, reveal that maximum solubility in self-dispersing whole milk powders could only be anticipated when using materials having bulk density of 0.36 g/ml. Further conversion of the data shows that the loss in solubility of milk solids in self-dispersing systems decreases slowly as the bulk density of the powders approaches .58 g/ml, and falls precipitously when this figure is exceeded.

DISCUSSION

Dispersing dry milk solids with sand and drawing water rapidly through the mixture may

be considered mechanically equivalent to dispersing milk solids throughout a volume of water with a stirrer. Using increasing amounts of sand to disperse the same amount of powder is equivalent to increasing the speed of stirring.

The data presented in this paper, therefore, substantiate Howat's claim (3) that the speed of stirring is more important than the duration of stirring used to disperse milk solids. High rates of stirring must necessarily keep the concentration of milk solids in the vicinity of the dissolving powder particle below levels which lead to destabilization of the milk protein system.

It is a common observation that any type of milk powder, in which the protein systems are not excessively damaged during production, can be rapidly dispersed by using high-speed mechanical stirrers. However, when very little or no agitation is applied to the dispersing system very few milk powders can be dispersed successfully.

Self-dispersion properties can be imparted to conventionally spray dried nonfat milk solids by producing irregular aggregates through wetting and redrying the powder. Bockian et al. (1) stated the improved dispersibility of this material might result from a translocation of osmotically active materials in the powder particles during the instantizing operation. This observation fails to account for the possible role of marked drop in bulk density of the product during instantizing and the fact that on grinding to reduce particle size and increase bulk density the instant dispersibility feature is completely lost.

This loss of dispersibility of a highly soluble milk powder on increase in bulk density by mechanical particle size reduction was also noted by Sinnamon et al. (9). High levels of dispersibility could not be obtained if vacuum-dried whole milk foams were broken through screens smaller than 20 mesh.

These observations strengthen our contention that the bulk density of milk powder must be considered as one of the quality-limiting factors in the production of self-dispersing milk powders. As the bulk density of approximately .40 g/ml is exceeded, additional mechanical energy must be supplied to effect complete solution of the milk solids.

A further test of this idea is to mechanically decrease the bulk density of a standard high bulk density material without change in composition. This was done by expanding conventional spray-dried whole milk powders by injecting pressurized nitrogen into the feed line of a conventional spray dryer. The low bulk

density material so produced had the expected improved dispersibility (2).

In whole milk powder particles the fat phase could possibly be considered a dispersing agent whose presence should improve the dispersibility of the powder particle. However, it has already been shown that the fat globules do not constitute an inert phase in milk (5) and that their presence in powders actually increases the difficulties encountered in dispersing milk powders.

The microscopic observation of the behavior of single milk powder particles dissolving in water and studies of motion pictures showing dissolving powder particles have shown that, on contact with water, the powder particles dissolve rapidly (7). As the content of the milk solids in the water increases, the speed of this process is reduced. In systems containing high levels of dissolved solids the particles wet and undergo changes which render them insoluble in part, since the salts and lactose they contain eventually go into solution.

From our data, and those cited, it is concluded that self-dispersing milk powders must necessarily be low bulk density materials unless made from milk chemically or physically modified before or during drying. The desired modifications would be made to stabilize the proteins present against loss in solubility during rehydration.

REFERENCES

- (1) BOCKIAN, A. H., STEWART, G. F., AND TAPPEL, A. L. Factors Affecting the Dispersibility of "Instantly Dissolving" Dry Milks. *Food Research*, 22: 69. 1957.
- (2) HANRAHAN, F. P., TAMMSMA, A., FOX, K. K., AND PALLANSCH, M. J. Production and Properties of Spray-Dried Whole Milk Foam. *J. Dairy Sci.*, 45: 27. 1962.
- (3) HOWAT, G. R., SMITH, J. A. B., WAITE, R., AND WRIGHT, N. C. Factors Affecting the Solubility of Milk Powders. IV. The Influence of Speed and Duration of Stirring on Solubility with a Description of a Rapid Method for Solubility Determinations. *J. Dairy Research*, 10: 498. 1939.
- (4) LEA, C. H., MORAN, T., AND SMITH, J. A. B. The Gas Packing and Storage of Milk Powder. *J. Dairy Research*, 13: 162. 1943.
- (5) LEVITON, ABRAHAM, AND PALLANSCH, MICHAEL J. High-Temperature Short-Time Sterilized Evaporated Milk. III. The Influence of the Lipid Phase on Heat and Storage Stability. *J. Dairy Sci.*, 44: 633. 1961.
- (6) MOJONNIER, J., AND TROY, H. C. *The Technical Control of Dairy Products*. 1st ed. pp. 120-129. Mojonnier Bros. Co., Chicago, Illinois. 1922.
- (7) PALLANSCH, M. J. Unpublished data.
- (8) PYNE, CHARLES HERBERT. Ph.D. thesis, University of Minnesota. 1961.
- (9) SINNAMON, H. I., ACETO, N. C., ESKEW, R. K., AND SCHOPPET, E. F. Dry Whole Milk. I. A New Physical Form. *J. Dairy Sci.*, 40: 1036. 1957.